## Automation for Operations

The management and operations of manned space missions is a complex and challenging undertaking requiring extremely skilled and knowledgeable engineers along with the application of tools to allow them the ability to plan and operate missions, and to anticipate, investigate and resolve problems. In the past, NASA's approach has been to rely on a large set of on duty and on call flight controllers to address operations needs. Furthermore, mission operations tools have been developed incrementally and independently in response to changing spacecraft configuration and mission needs. These tools are often not interoperable, leading to even more manual effort and training to use multiple tools and integrate their outputs. Finally, while astronauts and operators are overburdened, there have been few successful efforts to solve this problem by retrofitting technology due to real and perceived risk.

The Automation For Operations (A4O) project, funded by NASA's Exploration Technology Development Program, has prototyped an evolvable mission operations architecture to automate the operations of manned space vehicles, unmanned space vehicles, surface assets and robotic systems. The goals of the project are to achieve quantitative reductions in operations costs and increases in operations efficiency, while maintaining safety. Similar efforts to automate missions involving unmanned spacecraft have resulted in significant quantified benefits. Ground systems automation of the Mars Exploration Rover (MER) led to a 15 - 40% increase in efficiency. Ground systems automation of the Space Technology-5 mission and onboard automation for the Earth Observing-1 mission each led to cost savings in excess of 20%. Ground-based state monitoring was demonstrated on ST-5, and onboard state monitoring was demonstrated on Earth Observing-1. These successes have led to continued maturation of these technologies for both manned and unmanned space missions; however, current development efforts are not integrated, nor are they focused on Constellation.

The architecture supports crew on-board vehicles or in close proximity to robotic systems, as well as remote mission operations. It has a small number of reconfigurable components, clear component definitions, and interfaces for enabling information sharing. The architecture provides automation capabilities designed for use in a human spaceflight context. It is evolvable in support of varying and evolving mission needs, allowing Plug and Play insertion and removal of new and improved components in a manner preserving expected and trusted behavior of the system as a whole. Verification and validation is designed into the architecture to reduce the costs of re-certification as it evolves by employing data-driven modules, and on-line validation of operating instructions. The up-front investment in these technologies now will lead to major reductions in mission operations software cost and risk and increases in operational efficiency across Constellation elements.

In this paper we provide an overview of the A4O project and describe its accomplishments. We first provide a survey of human spaceflight mission operations, primarily from the perspective gained by NASA's Mission Operations Directorate (MOD) in operating the International Space Station (ISS). We describe the state of the practice of mission operations tools and the perspective of MOD regarding the drivers for increased automation in order to meet NASA's Constellation objectives. We then

describe the principal technology building blocks of the A4O project; automated planning, plan execution monitoring, verification and validation, and component interoperability. Each technology is used to build highly reconfigurable building blocks, which can then be composed into special-purpose applications to serve evolving mission needs. Finally, we describe the ways these building blocks have been demonstrated on a variety of relevant Constellation operations scenarios, and assembled into tools that have been used for ISS operations today.